

Fact sheet for “Identifying human influences on atmospheric temperature”

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Summary: We find some of the clearest evidence to date of a discernible human influence on atmospheric temperature. Satellite data and computer model simulations of historical climate change show common patterns of pronounced warming of the troposphere and cooling of the lower stratosphere. In the model simulations, these changes are mainly caused by human factors. We show that sustained, global-scale tropospheric warming and lower stratospheric cooling cannot be explained by natural climate variability. Our results are robust to current uncertainties in models and satellite observations.

Signal-to-noise analysis: A brief introduction

Our *PNAS* paper describes results from a climate change detection and attribution (“D&A”) study, in which we investigate the causes of temperature changes in Earth’s atmosphere. The focus of our study is on geographical patterns of temperature change in the troposphere and the stratosphere (see below):

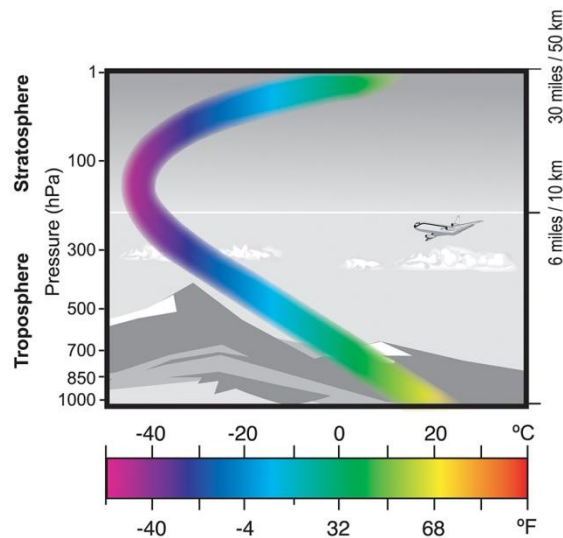


Figure 1: This Figure is from Synthesis and Assessment Product 1.1 of the U.S. Climate Change Science Program (*Karl et al., 2006*¹). It shows the approximate pressure and altitude boundaries of the troposphere and the stratosphere. The multi-colored line indicates the average dependence of temperature on altitude.

We rely on estimates of atmospheric temperature change from satellites and computer models of the climate system (“climate models”). The satellite observations are made available by three different research groups; the simulation output is from 20 individual models participating in phase 5 of the Coupled Model Intercomparison Project (CMIP-5).

The climate model results provide estimates of the atmospheric temperature changes expected to occur in response to a combination of human and natural factors (such as changes in greenhouse gases, aerosol particles, the Sun’s energy output, and volcanic activity). These expected changes are typically called the “fingerprint”. From a large number of previous studies, we know that human-caused changes in well-mixed greenhouse gases and stratospheric ozone are the most important influences on tropospheric and stratospheric temperature fingerprints.

¹Karl, T.R., S.J. Hassol, C.D. Miller, and W.L. Murray (eds.), 2006: *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, USA, 164 pp.

The model simulation output also gives us estimates of the year-to-year and decade-to-decade “noise” of internal climate variability, arising from such natural phenomena as the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO).

We use a standard fingerprint method² to search for the model signal pattern³ in the satellite observations. Our method quantifies the strength of the signal in observations, relative to the strength of the signal in natural climate noise. This yields so-called signal-to-noise (S/N) ratios. If the observed patterns of atmospheric temperature change are becoming increasingly similar to the model fingerprint pattern, and if the natural noise patterns are dissimilar to the fingerprint, the S/N ratios will be large. S/N ratios larger than 3 indicate that there is highly significant correspondence between the model fingerprint and satellite data, and that climate noise is unlikely to explain this pattern matching.

The S/N ratios we report on are given as a function of the length of the temperature record. Our primary focus is on S/N ratios over the full, 33-year period of the satellite data (1979 to 2011). Looking at longer periods of record helps to reduce the impact of large, year-to-year “noise”, and more clearly reveals any underlying signal. S/N ratios for relatively short periods of record (10 to 15 years) are typically smaller, and are dominated by interannual noise. Our summary of results (see below) is for the longest, 33-year temperature records.

²Our fingerprint method has been successfully employed for the identification of human effects on surface and atmospheric temperature, upper ocean heat content, the height of the tropopause (the boundary between the troposphere and stratosphere), and atmospheric moisture over oceans.

³Here, the signal is a geographical pattern of atmospheric temperature change.

Results of our S/N analysis: A brief summary

1. The lower stratosphere

In both satellite observations and the CMIP-5 simulations of historical climate change, the lower stratosphere cools markedly over the past 33 years. This cooling is primarily a response to the human-caused depletion of stratospheric ozone. Depending on the observational data set we use in our analysis, the S/N ratios for lower stratospheric temperature range from 26 to 36. To the best of our knowledge, these values are substantially higher than the S/N ratios reported in any previous climate change detection and attribution study.

2. The lower troposphere

The observations and model simulations show a common pattern of large-scale warming of the lower troposphere, with largest warming over the Arctic, and muted warming (or even cooling) over Antarctica. Tropospheric warming is mainly driven by human-caused increases in well-mixed greenhouse gases. The lower tropospheric S/N ratios range from 3 to 8, depending on which satellite data set we use. While these S/N ratios are smaller than for stratospheric temperature changes, they are still highly significant.

3. Why do we obtain these large S/N ratios?

The large S/N ratios tell us that the observed atmospheric temperature changes over the satellite era are becoming increasingly similar to model fingerprints, and are dissimilar to the main patterns of internal climate noise. In other words, the observations and fingerprint patterns show global-scale cooling of the lower stratosphere and global-scale warming of the lower troposphere, while the dominant patterns of climate noise do not show such large-scale temperature changes.

4. Are our S/N ratios biased by model errors in estimates of climate noise?

If the CMIP-5 models analyzed here systematically underestimated the size of observed climate noise, our S/N ratios would be spuriously inflated. We find no evidence that this is the case. To test the fidelity with which models simulate observed variability, we compared modeled and observed temperature fluctuations on decadal timescales.⁴ On average, the CMIP-5 models substantially overestimate the size of observed tropospheric temperature variability, suggesting that our tropospheric S/N ratios are probably too conservative. In the lower stratosphere, the size of modeled and observed decadal variability is (on average) very similar.

⁴This analysis used digitally-filtered temperature data; the filtering highlighted temperature variability on timescales ranging from 5 to 20 years.

5. Are these results driven solely by large global-mean changes?

We addressed this possibility by removing the global-mean temperature change from each data set before performing the S/N analysis. In the troposphere, in over 50% of the cases we considered, S/N ratios remain highly significant. This shows that correspondence between the model fingerprint and observations is not solely due to a common global-mean warming signal, but also to common patterns of temperature change. In the lower stratosphere, however, S/N ratios are not significant when global-mean information is removed.

6. The Higgs boson, and the meaning of a “five sigma” result

In recent news coverage of the discovery of the Higgs boson, there has been considerable public discussion of the significance of a “five-sigma” result.⁵ In our *PNAS* paper, the lower stratospheric temperature changes over 1979 to 2011 yield results at the 26 to 36 sigma level. These values are surprisingly large – as is our estimated 5.5 sigma result for the strength of the model-predicted fingerprint in the two publicly-available satellite records of lower tropospheric temperature changes. In terms of identifying a human-caused fingerprint in satellite records of atmospheric temperature change, our findings suggest that we are already beyond the “five-sigma” threshold.

7. Are there still unresolved issues?

Yes. Although we found a “pattern match” between modeled and observed atmospheric temperature changes, most models have problems capturing the size of the observed changes. On average, the CMIP-5 models underestimate the observed cooling of the lower stratosphere, and overestimate the warming of the troposphere. Some scientists have claimed that there is only one possible interpretation of such differences – that models are too sensitive to greenhouse gas increases. Such claims are incorrect. There are multiple interpretations of differences between modeled and observed temperature changes. Other possible explanations include: A) residual errors in the observations; B) an unusual sequence of natural climate fluctuations in the observations; and C) the neglect or inaccurate specification of key “forcings” in model simulations of historical climate change. Results presented here and elsewhere suggest that forcing errors make an important contribution to the biases in model temperature trends.⁶

⁵See, for example, <http://physicsbuzz.physicscentral.com/2012/07/does-5-sigma-discovery.html>

⁶Note that these biases have relatively small impact on the “model-versus-observed” S/N results presented here (see discussion on lines 825-832). This is because the searched-for fingerprint patterns are normalized – thus reducing the effect of biases in the size of modeled temperature changes.